DOES THE SUM OF THE PARTS EQUAL THE WHOLE: RELATIONSHIPS BETWEEN EXECUTIVE FUNCTION, VISUAL ATTENTION AND HEART RATE VARIABILITY IN ROTC CADETS

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ABSTRACT

The prefrontal cortex of the brain filters a variety of competing demands in order to appropriately execute goals and intentions (Cooper & Shallice, 2000). This region is also critical for controlling visual attention (Stuss, Shallice, Alexander, & Picton, 1995) and regulating the autonomic nervous system and heart rate variability (HRV) (Thayer & Lane, 2000). Each of these processes has been examined separately, but none have explored the relationships among them. The current study examined visual attention, executive functioning, and HRV in undergraduate ROTC cadets. Forty-one cadets participated in this study wherein executive function was measured via self-report questionnaires, visual attention was assessed with a modified Flanker task, and HRV was measured twice weekly over a twelve-week period. Results revealed a moderate relationship between participants' executive function (particularly those items related to behavioral regulation) and HRV. However, neither reaction time nor accuracy on the modified Flanker task was associated with HRV.

DEDICATION

For Michelle, without whom I would never have known that family does not have to be blood.

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LIST OF ABBRIEVIATIONS

EF, Executive Function

ROTC, Reserve Officer Training Corps

PFC, Prefrontal cortex

BRIEF-A, Behavioral Rating Inventory of Executive Function- Adult

SAS, Supervisory Attention System

CS, Contention Scheduling System

RT, response time

HRV, Heart Rate Variability

RMSSD, root mean square of successive differences

CHAPTER I

INTRODUCTION

Success in activities of everyday life involves selecting goals, monitoring progress towards those goals, and prioritizing behaviors to achieve them. These goal-directed behaviors require executive function, selective attention, and behavior regulation, which are dependent upon functional connectivity within the prefrontal cortex and between the prefrontal cortex and the other regions of the brain (D. T. Stuss et al., 1995). The prefrontal cortex plays a pivotal role in the assessment of and adaptation to environmental stimuli, using that stimulus information when regulating the autonomic nervous system and influencing heart rate variability (HRV) (Thayer & Lane, 2000). Given the convergent role of the prefrontal cortex for affecting both executive function and the autonomic nervous system, this study examined whether a relationship exists between heart rate variability, selective visual attention, and executive function in Reserve Officer Training Corps (ROTC) cadets at the University of Tennessee at Chattanooga.

The Executive Functions and the Frontal Lobes

While over 30 conceptual definitions of executive function (EF) exist, most agree that EF allows for completing goal directed behaviors (Banich, 2009; Bianchi, 1895; Gioia, Isquith, & Guy, 2001; Luria, Karpov, & Yarbuss, 1966; Welsh & Pennington, 1988). Indeed, EF is often used as an umbrella term to encompass many cognitive processes such as attention, planning, initiation, working memory, self-monitoring, and behavioral regulation (Goldstein, Naglieri, Princiotta, & Otero, 2014). Neuroimaging, behavioral studies, and even the infamous case of Phineas Gage clearly demonstrate that EF is dependent on the proper functioning of the brain's frontal lobes, and more specifically, the prefrontal cortices (Corbetta & Shulman, 2002; Levine, Turner, & Stuss, 2008; Miyake et al., 2000; Ratiu, Talos, Haker, Lieberman, & Everett, 2004; Stuss, 2011).

The prefrontal cortex (PFC) is the most anterior portion of the brain, and while it is highly interconnected with other brain structures (Cummings, 1995), the functional connectivity of regions within the PFC helps distinguish the nuances of executive function (Petrides & Pandya, 2002). The PFC is anatomically subdivided into several regions: the orbitofrontal cortex; the dorsolateral prefrontal cortex; the dorsomedial prefrontal cortex; the ventrolateral prefrontal cortex; and the ventromedial prefrontal cortex, which includes the anterior cingulate cortex. Three of these areas are associated with dissociable executive processes: the left dorsolateral prefrontal cortex is involved in integrative activities and task-setting (e.g., integrating the spatial position of a stimulus with one's task instructions), the right dorsolateral prefrontal cortex is involved in monitoring task performance (e.g., sustaining attention), and the dorsomedial prefrontal cortex is involved in inhibitory control and behavior regulation (Shackman, McMenamin, Maxwell, Greischar, & Davidson, 2009). Together with structures within the basal ganglia, these three sections of the PFC form the dorsolateral prefrontal – subcortical circuit that supports EF (Pripfl & Lamm, 2015).

Individuals who sustain damage to the dorsolateral prefrontal – subcortical circuit can display a broad variety of executive and attention deficits. Patients with acquired brain injury commonly report issues with planning, working memory, strategy use, and distractibility as measured by the Dysexecutive Questionnaire (Bennett, Ong, & Ponsford, 2005) and the Behavioral Rating Inventory of Executive Function – Adult (BRIEF-A; Roth, Isquith, & Gioia, 2005). In addition, self-reported executive ability, as measured by the global composite score on the BRIEF-A, significantly predicts distractibility and attention capture while driving in even healthy participants of all ages (Morris & Dawson, 2008; Pope et al., 2017). Together, this suggests interconnectivity between executive and attentional networks which is supported by Posner and Petersen's (1990) theory of attention. Their theory indicates that attention is not a singular phenomenon. Instead, attention is only possible because of a series of independent cognitive processes, each controlled by interconnected neural networks.

A variety of activities of daily living demonstrate support for Posner and Petersen's (1990) theory. For example, a person rarely thinks about the act of shifting balance between the limbs while walking; walking is performed automatically. However, other everyday actions like driving a car require focused attention. In fact, without focused attention while driving, profound mistakes can occur. Therefore, a complex attention system must exist to control distribution of attention resources. Cooper and Shallice (2000) theorize that control of attention is maintained through both purposeful and automatic direction of resources. Their theory involves two separate, but cooperative, systems. One of the systems is called the supervisory attentional system (SAS) and it is associated with purposeful direction of attention for the completion of non-routine and novel behavior. The other system is called the contention scheduling system (CS) and it is associated with control of attention for the completion of relatively routine, habit-driven behaviors. Very few attention resources are allocated to the CS for well-learned, routine behaviors while more robust resources are allocated to the SAS to support behaviors that are novel and require consistent monitoring, and/or actions that may involve changing demands and inhibition or switching.

The SAS and CS work together to accomplish goal-directed behavior(Cooper & Shallice, 2000)) and the interplay between the systems is controlled by executive function. Switching between SAS and CS control is efficient because novel or salient situations that rely on the SAS for monitoring, constant updating of working memory, and inhibition deplete regulatory resources at a higher rate than familiar, low effort situations that rely on the CS (Muraven & Baumeister, 2000). Additionally, those who demonstrate better ability to switch efficiently between attention control systems are also better able to respond adaptively to environmental stimuli.

Selective Visual Attention

Within the visual modality, attention allows for rapid detection and localization of stimuli within the environment (visual scene/display). At any given time, there is a vast amount of information being processed at a sensory level. Individuals must often divide their visual attention across central and peripheral stimuli to detect relevant targets within a visually cluttered environment (Lunsman et al., 2008). Generally, stimuli that are located centrally are allocated more focused and deliberate attention while information that is located peripherally is attenuated (Sanders, 1970). However, the physical and semantic salience of the information within the visual environment, coupled with an individual’s unique goals, will ultimately determine which elements of the visual environment are deemed task-relevant, and therefore allocated more attention resources.

The presence of distractors can exacerbate visual attention demands and reduce the efficiency of the SAS and CS systems. Indeed, reduced accuracy and slower response times are consistently observed on the Eriksen Flanker task when targets are presented with distracting information, namely incongruent flanker arrows (Heitz & Engle, 2007). Also, accuracy is even more reduced on trials where participants are forced to prioritize speed. Biggs and Gibson (2018) demonstrated that undergraduate participants' performance on a modified version of the Erikson Flanker task was impacted not just by the presence of incongruent flankers, which they classified as central distractors, but also by the presence of peripheral distractors.

This impact of distractors is observed even for individuals who are highly trained at processing visual stimuli. For example, Esterman and colleagues (2013) studied veterans while they completed a visual search task that was made especially challenging because some non-targets were presented in a different color, making them more salient and distracting. In the presence of these distractors, even trained veterans demonstrated slower average reaction times (RTs) to targets. This supports the assertion that visually salient distractors capture attention and partially deplete the efficiency of the attention control system for completing goal-directed behavior.

Heart Rate Variability

Assessment of and adaptation to environmental stimuli, inhibition of distractors, and aspects of executive function are controlled by activity within the PFC. This region is also instrumental in regulating the autonomic nervous system. Specifically, the PFC influences heart rate variability (Thayer & Lane, 2000). Heart rate variability (HRV) assesses the beat to beat change(s) in the heart and reflects the reactivity of the autonomic nervous system. That is, HRV is an indicator of how efficiently the body can switches between the sympathetic nervous system, where heart rate becomes elevated and blood pressure rises, and the parasympathetic nervous system, where heart rate slows in order to return the body to a restful state (Acharya, Joseph, Kannathal, Min, & Suri, 2007).

Efficient switching between these systems is associated with good HRV and is also related to an adaptable, healthy nervous system (Levy, 1990). Indeed, those with better HRV exhibit fewer executive difficulties and better behavioral control (Hovland et al., 2012) as well as faster responding to visual stimuli (Park et.al., 2013). Conversely, mood disorders and behavioral dysregulation are more common in those with poor HRV (Kagan, Reznick, & Snidman, 1987; Thayer, Friedman, Borkovec, Johnsen, & Molina, 2000).

HRV measurement

HRV can be assessed in several ways but the most commonly used method is to record cardiac vagal tone (Task Force, 1996; Thayer and Lane, 2000). Tonic cardiac vagal tone (tonic HRV) is the beat-to-beat interval of an individual’s heart rate while at rest (Berntson, et al., 1997). Higher tonic HRV indicates a more efficient nervous system; indeed, individuals with higher tonic HRV demonstrate better cognitive and physical performance (Martin, 2007; Peschel, 2016; Stein et al., 2005). Another HRV indicator is phasic HRV, which represents the variability in tonic HRV over multiple time points. Higher phasic HRV is helpful only if a mental or physical stressor is present at one or more of the measurement points (Porges, 2007). Otherwise, high phasic HRV reflects instability of HRV over time and is maladaptive because it represents inefficient switching between the sympathetic and parasympathetic nervous systems.

Park and colleagues (2014) examined how tonic and phasic HRV are associated with visual attention in a task that featured distractors that induced fear (emotionally present or emotionally neutral faces). When emotionally charged distractors were present, greater attention demands were required, and on average, participants had lower tonic HRV. However, those participants who maintained higher tonic HRV during the task experienced phasic HRV enhancement in the no-distractor condition and even had an absence of phasic suppression when the distractors were present. Therefore, those who possessed better HRV were better able to attend to the stimuli presented even when there were greater attention demands.

Influence of HRV on Goal Directed Behavior

We must engage foundational skills (e.g., goal-setting, behavior regulation), cognitive skills (e.g., attention, imagery), and psychosomatic skills (e.g., fear control, relaxation) to complete goal-directed behaviors (Hammerstein, Pickering, McGraw, & Ohlson, 2010; Ward et al., 2008). Many of these abilities are positively associated with HRV. Indeed, while support for relationships between visual attention and HRV (Park & Thayer, 2014 Thayer & Lane, 2000), as well as EF and visual attention (Norman & Shallice, 2000; Posner & Petersen, 1990), exist within the literature, scarce literature exists exploring the correlations among all three domains. In this study, I assess the relationships among 1) self-reported ability to successfully engage in goal-directed behavior (executive function), 2) ability to sustain visual attention and respond accordingly across a variety of competing demands (visual attention), and 3) HRV in students from the University of Tennessee who are engaged in the ROTC program.

First, I hypothesize a) a negative correlation between self-reported measures of EF difficulty and HRV, such that individuals who report less frequent EF difficulty will experience greater tonic HRV. However, I also hypothesize that b) less frequent EF difficulty will be positively correlated with lower (more stable) phasic HRV. Second, I hypothesize a) a positive correlation between selective visual attention and HRV, such that individuals who demonstrate greater accuracy and faster responses on a visual attention task will also experience greater tonic HRV. Additionally, I hypothesize that b) greater accuracy and faster responding will be negatively correlated with lower (more stable) phasic HRV.

CHAPTER II

METHODOLOGY

Participants

Forty-one participants were selected from a group of 73 ROTC cadets. These participants were selected because their commanding officer perceived them to be highly dependable and therefore likely to be present for every data collection session. All 41 of the participants (32 male, nine female) were English-speaking. They ranged in age from 18 – 32 years old (M = 20.76, SD = 2.49). Out of all participants, 92.7% identified their ethnicity as Non-Hispanic/Latino and 4.9% identified as Hispanic/Latino. Additionally, 80.5% identified their race as White/Caucasian, 9.8% as Black/African-American, and 4.9% as more than one race. Thirty-three participants reported no history of neurological, cardiovascular, and/or psychological conditions and the remaining either reported personal history with an attention disorder (n = 2), mood disorder (n = 5), or learning disability (n = 1). Further, 34.1% of participants reported personal history of experiencing at least one concussion.

Thirty-nine of the 41 participants completed all components of the study. One participant was unable to complete the visual attention task and one participant was unable to complete the EF questionnaires. Every participant received a $15 Amazon gift card in appreciation of their participation in the study.

Measures

Self-reported executive function

The Behavior Rating Index of Executive Function-Adult (BRIEF-A) (Roth et al., 2005) is a 75-item questionnaire that captures an individual's perceived executive function difficulties in everyday life. The BRIEF-A includes questions designed to measure executive skills such as inhibition, initiation, planning and organizing, task monitoring, and emotional control. Participants were asked to endorse behaviors using one of three response choices: never (0), sometimes (1), or often (2). Three composite scores are generated from the answers to the 75 items: the Behavioral Regulation Index composite score, the Metacognition Index composite score, and a Global Executive Composite. The Behavioral Regulation Index is comprised of responses to items that pertain to one's ability to engage in inhibition, set-shifting, emotional control and self-monitoring. The Metacognition Index is comprised of responses to items that pertain to initiation, working memory, planning/organizing, and task monitoring. Finally, the Global Executive Composite is a summation of the scores from the two aforementioned indices.

Higher scores on the BRIEF-A Global Executive Composite, Behavioral Regulation Index or Metacognition Index suggest higher frequency of perceived executive difficulties specific to the executive skills encompassed within the respective subscale. In the current study, high internal consistency was observed within the Behavioral Regulation Index ($\alpha = .93$), Metacognition Index ($\alpha = .96$), and Global Executive Composite ($\alpha = .95$),

The Self-Regulation Scale (Schwarzer, Diehl, & Schmitz, 1999) is a 10-item questionnaire that measures components of executive function including, self-regulation, goal pursuit, and self-efficacy. An example question is "I can concentrate on one activity for a long time, if necessary." Responses are measured on a four-point Likert scale that ranged from not true at all (1) to exactly true (4). Three of the items within this scale are negatively worded (e.g., “When I worry about something, I cannot concentrate on an activity”) and were reverse-coded before summating the final score. A higher total score on the Self-Regulation Scale indicates better perceived self-regulatory abilities. This measure has previously demonstrated acceptable test-retest reliability ($r = 0.62$) as well as good discriminant and convergent validity in other populations (Schwarzer et al., 1999). In the current study, acceptable internal consistency was observed ($\alpha = .79$).

The Dysexecutive Questionnaire (Burgess, Alderman, Evans, Emslie, & Wilson, 1998) is a 20-item measure of executive dysfunction. Questions are tailored to four categories of executive ability: emotional/personality, motivation, behavior, and cognitive. An example question is “I have difficulty thinking or planning ahead for the future” and “I have trouble making decisions or deciding what I want to do." All questions are answered on a four-point Likert scale ranging from zero (*never*) to four (*very often*). Scores across all 20 items were summed with higher total scores suggesting greater perceived executive difficulty. In the current study, high internal consistency was observed for this measure ($\alpha = .94$).

Visual attention

Selective visual attention, inhibition, and overall response speed was measured using a modified Flanker task (Eriksen & Eriksen, 1974). The traditional Flanker stimuli of five arrows (e.g., >>>>>, <<<<<) were presented on a small screen centered in a Dynavision D2 System (Klavora, Gaskovski, & Forsyth, 1994). The Dynavision apparatus consists of a wall-mounted board that has 64 response buttons arranged in five concentric rings. The Dynavision apparatus records response times with precision to a hundredth of a second. Moreover, the tool has been used in a variety of studies, including clinical rehabilitation, sports vision training, driver retraining, and concussion management (Klavora et al., 1994). It has demonstrated excellent reliability and validity evidence in measuring response times (Klavora et al., 1994).

For the modified Flanker task, participants were instructed to maintain eye fixation directly in front of them where target arrows were presented with either congruent (>>>>>) or incongruent flankers (>><>>). Each trial was displayed for 200 milliseconds. When the arrows were presented, two response buttons became illuminated, one on the left and one on the right of the centrally placed stimuli. The participant was required to selectively attend to the pointed direction of the central target arrow and press the illuminated button that corresponded with that pointed direction. For example, when the central arrow pointed in the left direction (<<<<<), the participant should press the illuminated button on the left. Immediately after the button was pressed for that trial, a subsequent trial begins containing another set of five arrows. In circumstances where the flanking arrows are congruent, no inhibition of distractors is required, consistent with the original Flanker task. In fact, congruent flanking arrows are generally associated with faster and more accurate responses. However, where the flanking arrows are incongruent, participants must inhibit the meaning of those stimuli and focus only on the central target. Generally, accuracy is lower and response times are slower for these incongruent trials.

The variables of interest from the modified Flanker task include average response time for all trials (overall RT), average response time for incongruent trials (incongruent distractor RT), and the difference in response time between congruent and incongruent trials (performance cost). Accuracy of congruent versus incongruent trials is often also explored with the Flanker task.

Heart rate variability

Heart rate variability was measured using Elite HRV Corsense sensors. The Corsense sensor measured the individual's beat-to-beat interval of heart rate (Gil et al., 2010). The Corsense sensor was affixed to the end of the participant's finger and sensor data was transmitted via Bluetooth to the Elite HRV smartphone application. When calculating tonic or phasic HRV, a minimum 60-second recording demonstrates reliable comparability of results to the gold star measurement of HRV, five-minute collections of RMSSD (Esco & Flatt, 2014; Malik, 1996). The Corsense monitor was preset to record a two-minute HRV reading for each participant every data collection day. The smartphone application was securely linked with the HRV Elite Dashboard website where each participant's data was aggregated into an output file. The output file provided a variety of HRV metrics, two of which are the focus of this study: a measure of tonic HRV, the root mean square of successive differences (RMSSD) and a measure of phasic HRV, the RMSSD coefficient of variation. RMSSD is an indicator of the responsivity of the autonomic nervous system but it is typically not normally distributed. Therefore, RMSSD was transformed to the natural log RMSSD (lnRMSSD). In addition, the coefficient of variation for lnRMSSD was calculated by dividing the standard deviation of a participant's lnRMSSD by their mean. The coefficient of variation represents the intraindividual variability of their RMSSD measurement. Therefore, this phasic HRV indicator reflects the stability of the HRV over time.

Mood, sleep, and psychological resilience

This research project was part of a larger study that sought to understand how HRV is associated with a variety of psychological indicators. Consequently, mood, sleep quality, and psychological resilience were also assessed. The Center for Epidemiologic Studies Depression

Scale (Radloff, 1977) is a 20-item, self-report questionnaire that examines depressive affect and mood. Answering each of the 20 items (e.g., "*My sleep was restless"; "I felt fearful"; "People were unfriendly")* requires the participant to reflect on the past week and rate how they felt on a four-point Likert scale ranging from 0 ("*Rarely or none of the time"*) to 3 ("*Most or all of the time"*). Before summing the items' ratings to compute the total score, positively worded items (e.g., "*I was happy"*) are reverse-scored. This leads to a total score that can range from 0 (the lowest score possible) to 60 (the highest score possible). Higher scores on the Center for Epidemiologic Studies Depression Scale indicate greater depressive affect and/or mood.

The Pittsburgh Sleep Quality Index (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989) assesses individuals' sleep quality and sleep disturbances over the past month with 19 items to produce a global sleep quality score as well as seven component scores in the areas of sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbance, use of sleeping medications, and daytime dysfunction. The first four questions on this scale are open-ended (e.g., What time do you usually go to bed?; How long has it taken to fall asleep?) and the subsequent questions are answered on a four-point Likert scale ranging from 0 (*not during this past month*) to 3 (*three or more times per week*). The global sleep quality score can range from 0 to 7 where higher scores indicate poorer sleep quality.

Finally, the Connor-Davidson Resilience Scale (Connor & Davidson, 2003) measures resilience with 25 self-report items (e.g., I can see the humorous side of things; I am not easily discouraged by failure) using a five-point Likert scale ranging from 0 (*strongly disagree*) to 4 (*strongly agree*). Scores are summed and can range from 0 to 100 where higher scores indicate a greater level of resilience. This measure of resilience is correlated with aspects of behavioral-regulation, specifically the ability to efficiently task-switch (Connor & Davidson, 2003).

Procedure

To limit the logistical burden on the ROTC participants, assessments for this study were conducted in two parts. Part One involved collecting HRV measurements twice weekly throughout most of the Spring 2019 semester. Part Two involved participants completing the modified Flanker task and self-report questionnaires.

Part one

All participants provided informed consent on the first day of HRV collection. Over a 12-week period, HRV data was collected every available Monday and Wednesday, between 5:30 and 6:05 AM. Upon arrival to each session, participants were instructed to sit in a chair in a common room and to refrain from any physical movement for 60 seconds, as a seated position increases the accuracy of capturing the resting heart rate in each data collection (Camm et al., 1996). Subsequently, the participant was fitted with the first available heart rate sensor (generally onto the right index finger) and instructed to close their eyes and refrain from physical movement while the sensor was recording.

Figure 2.1 Elite Corsense finger sensor and accompanying device-based application

The sensor was worn until an auditory prompt signaled the experimenter that enough data was acquired for an accurate HRV calculation. Acquisition of valid HRV data requires at least 60 seconds of continuous heart rate data. For this study, the average duration of an HRV collection across readings was 60.1 seconds.

Part two

All participants provided informed consent for the second section of the study during their testing timeslot. Timeslots were available between 6:00 AM and 12:00 PM on Monday, Wednesday and Friday of the second week of February 2019. Based on the number of devices (i.e., iPads, Dynavision) available at any time, participants began the session with either the questionnaires or the modified Flanker task. The questionnaires were administered using Qualtrics survey software in the following order: mood; sleep quality; Self-Regulation Scale; resilience; Dysexecutive Questionnaire; BRIEF-A; and demographic questions. Upon completion of the questionnaires, participants were prompted to notify an experimenter who then accompanied them to the Dynavision D2 apparatus for the modified Flanker task.

For the Flanker task, participants were instructed to stand directly in front of the Dynavision D2 board (see Figure 2.2). The apparatus was adjusted to display the centrally located liquid crystal display monitor (where the arrow stimuli were displayed) at the participant's eye level. Additionally, participants were instructed to position themselves centrally to the board such that they could reach all of the 64 buttons with ease.

Figure 2.2 Dynavision apparatus for modified Flanker task

Before beginning the modified Flanker portion of the task, participants were provided the opportunity to familiarize themselves with the apparatus and the movement involved with pressing all the buttons on the apparatus. In this section, participants were instructed that a button would illuminate one at a time and they should "Hit only the buttons on the board that illuminate and do so as fast as you can." During this section, a button on the Dynavision board illuminated. The participant would press that button; then, another button in a random location would illuminate and the participant would react and press to the deactivate that light. This cycle continued until the participant pressed all 64 buttons, in random order. Only then did the participant move on to the modified Flanker portion of the study.

During the modified Flanker portion, the participant was told that, "Within the display screen, you will be presented with a series of five arrows. Only pay attention to the direction of the central arrow. If the central arrow is pointing right, hit only the illuminated button located on the right side of the board. If the central arrow is pointing left, hit only the illuminated button that is located on the left side of the board. Once shown the arrows, please hit the correct illuminated button as quickly as possible." The participant was asked if they understood the instructions and were given an opportunity to complete a series of practice trials. Eighteen of the 40 participants had previous experience with this assessment as part of a different study conducted by the Athletic Training department at UTC. Therefore, the required practice run was only administered to those with no prior experience with this assessment (n = 22). Each trial began with the display of five arrows, and concurrently, both left and right illuminated buttons appeared on the same concentric ring. The participant was required to assess the pointed direction of the central arrow and press the corresponding illuminated button. Immediately after the button press, another trial commenced. This task continued until all 48 trials were completed, 24 congruent and 24 incongruent.

After completion of the modified Flanker task, participants who had completed the questionnaires first were dismissed from the testing area. Those who were randomly assigned to complete the Flanker task first were accompanied to the area of the testing facility where the questionnaires were administered. In total, Part Two of the study took approximately 70 minutes to complete.

CHAPTER III

RESULTS

Data Cleaning

Data from 41 participants was obtained through measures of executive function, visual attention and HRV. One participant failed to complete all self-reported measures, excluding them from analysis. Participant data were excluded from all BRIEF-A scaled scores when criteria was met for excessive negative responding (Negativity), inconsistency of responding to similar items (Inconsistency), and/or frequency of atypical responses (Infrequency) (Roth et al., 2005). No participants in this study met exclusion criteria for the Negativity component, but five participants met criteria for Infrequency, and one participant met criteria for Inconsistency, therefore their BRIEF-A data was removed from the sample. In total, BRIEF-A data from 33 participants were included in analyses.

Regarding the Dysexecutive Questionnaire, two participants failed to answer a select number of the items and their missing scores were replaced through mean imputation. Three participants' self-report Dysexecutive Questionnaire data were excluded for homogeneity of responses and two participants were excluded for scoring at least two standard deviations from the mean. In total, 35 participants executive functioning data measured by the Dysexecutive Questionnaire was included in the analyses. When participant data met exclusion criteria for both the BRIEF-A and Dysexecutive Questionnaire measures, their Self-Regulation Scale data was also removed. In total, Self-Regulation Scale data from 39 participants were included in analyses.

Reasons for removal of data collected using the visual attention task were as follows: Participant failed to complete the modified Flanker task (*n* = 1) or scored more than two standard deviations from the mean for any response time measure (*n* = 1). Regarding rate of accuracy, 75% of participants in this study scored at ceiling level. In total, visual attention data from 39 participants were included in analyses.

Acquisition of valid HRV data requires at least 60 seconds of continuous heart rate data therefore any HRV data point that had fewer than 60 seconds of acquisition time was removed from analyses. In total, 97 of 581 HRV data points were removed for this reason. Once those data points were removed, the average acquisition time within the remaining sample was 61.9 seconds (range: 60-119.33). Three participants had only four or fewer valid data collection days after removal of all data points with unacceptable acquisition time so their data was not included in any further HRV analyses. Two more participants were excluded from analysis for having z-scores outside the normal range (z = 2.29 and 3.69, respectively). In total, HRV data from 38 participants was included in the analyses.

Hypotheses One and Two

Shapiro-Wilk tests were performed to assess normality for all variables used in this study. Non-normal distributions were demonstrated in tonic HRV (p = .013), BRIEF-A Global score, (p = .009) the Behavioral Regulation Index score (p = .038) and Metacognition Index score (p = .008). The natural logarithm of RMSSD (lnRMSSD) passed tests of normality, therefore lnRMSSD was used when analyzing tonic and phasic HRV. Due to significance within tests of normality, the non-parametric correlational method, Spearman-*rho*, was employed when using these variables in data analysis. Means and standard deviations of all variables used in the first hypothesis analyses can be found in Table 3.1.

Table 3.1 Hypothesis one descriptive statistics

	N	*M*	*SD*
BRIEF-A Global Score	33	28.67	23.33
BRIEF-A Behavioral Regulation Index	33	12.36	9.82
BRIEF-A Metacognition Index	33	16.30	14.88
Self-Regulation Scale	39	22.26	3.60
Dysexecutive Questionnaire	35	14.54	9.57
Tonic HRV	38	4.38	0.39
Phasic HRV	38	0.07	0.03

M = average, *SR* = standard deviation

Executive function and HRV

As anticipated, significant associations were found between measures of executive function. Specifically, strong negative relationships were observed between the BRIEF-A global score and the Self-Regulation Scale (r_s (33) = -.74, $p < .001$, r^2= .55), and between the Self-Regulation Scale and the Dysexecutive Questionnaire (r_s (36) = -.64, $p < .001$, r^2 = .41). A strong, positive relationship was observed between the BRIEF-A Global score and the Dysexecutive Questionnaire (r_s(33) = .84, $p < .001$, r^2 = .70). Significant associations were demonstrated between measures of HRV. A moderate, negative relationship was found between tonic HRV and phasic HRV (r_s (36) = -.77, $p < .001$, r^2 = .59).

The first series of hypothesis-based analyses examined the relationships among executive function and HRV. A negative relationship was observed between tonic HRV and BRIEF-A Behavioral Regulation Index (r_s(26) = -.35, $p < .05$, r^2 = .12). While relationships between tonic

HRV and BRIEF-A Global score and Metacognition Index were in the expected direction, they did not reach statistical significance (BRIEF-A Global score $r_s(26) = -.22$, $p > .05$; BRIEF-A Metacognition, $r_s(26) = -.13$, $p > .05$). (See Table 3.2)

Table 3.2 Correlations between BRIEF-A and HRV

	1	2	3	4	5
1. Tonic HRV	--				
2. Phasic HRV	-.77*	--			
3. Behavior Regulation Index	-.35*	.50*	--		
4. Metacognition Index	-.13	.35*	.80*	--	
5. BRIEF Global Score	-.22	.39*	.92*	.95*	--

Note: *$p < 0.05$, one-tailed

Significant relationships were observed between phasic HRV and executive function. Moderate, positive relationships were found between phasic HRV and the BRIEF-A Global score ($r_s(26) = .39$, $p < .05$, $r^2 = .15$); BRIEF-A Behavioral Regulation Index ($r_s(26) = .50$, $p < .05$, $r^2 = .25$); and BRIEF-A Metacognition Index ($r_s(26) = .35$, $p < .05$, $r^2 = .12$) (See Table 3.2). Within the Behavioral Regulation Index, significant mean differences were found in those that were above the sample median phasic HRV (*median* = .07) and those that fell below the sample median for phasic HRV ($t(28) = 2.21$, $p < .05$, $d = .41$) Other relationships between phasic HRV and executive function failed to reach statistical significance (phasic HRV and Dysexecutive Questionnaire ($r_s(26) = .05$, $p > .05$); Self-Regulation Scale ($r_s(26) = -.01$, $p > .05$) (see Table 3.3).

Table 3.3 Correlations between other EF measures and HRV

	1	2	3	4
1. Tonic HRV	--			
2. Phasic HRV	-.77**	--		
3. Self-Regulation Scale	-.07	-.01	--	
4. Dysexecutive Questionnaire	.02	.05	-.46**	--

Note: ***p* < 0.01, one-tailed

Visual attention and HRV

Shapiro-Wilk tests of normality were non-significant for all measures of HRV and visual attention. Therefore, the data was normally distributed and Pearson's *r* were selected to analyze potential relationships between HRV and visual attention. Means and standard deviations of all variables used in the second hypothesis analyses can be found below in Table 3.4.

Table 3.4 Hypothesis two descriptive statistics

	N	*M*	*SD*
Overall RT	39	919.00	0.10
Congruent RT trials	39	879.00	0.10
Incongruent RT trials	39	952.00	0.11
RT Performance costs	39	-7.30	0.07
Tonic HRV	38	4.38	0.39
Phasic HRV	38	0.07	0.03

M = average, *SD* = standard deviation, all RT reported in *ms*

The second series of hypothesis-based analyses examined the relationships among visual attention and HRV. Tonic and phasic HRV failed to significantly correlate with visual attention. Relationships in the expected direction exist between HRV and visual attention, but failed to reach significance between tonic HRV and visual attention (overall RT ($r(34) = -.09$, $p > .05$); mean incongruent RT ($r(34) = -.08$, $p > .05$); performance costs ($r(34) = .12$, $p > .05$). Similarly, no relationship between phasic HRV and visual attention reached significance (mean overall RT, ($r(34) = -.03$, $p > .05$); mean incongruent RT, ($r(34) = -.10$, $p > .05$); and performance costs, ($r(34) = -.01$, $p > .05$) (see Table 3.5).

Table 3.5 Correlations between visual attention and HRV measures

	1	2	3	4	5	6
1. Mean Overall RT	--					
2. Mean RT Congruent Trials	.89**	--				
3. Mean RT Incongruent Trials	.93**	.75**	--			
4. Performance Costs	-.13	.19	-.39**	--		
5. Tonic HRV	-.09	-.13	-.08	-.01	--	
6. Phasic HRV	-.02	.07	-.05	.18	-.77**	--

Note: ***p* < 0.01 , one-tailed

Relationships were found between executive function, as measured by the Dysexecutive Questionnaire and BRIEF-A and visual attention. A significant negative relationship was found between the Dysexecutive Questionnaire and overall RT ($r_s(33) = -.35$, $p = <.05$, $r^2 = .12$). Relationships between visual attention and other measures of executive function failed to reach significance (see Table 3.6).

Table 3.6 Correlations between visual attention and EF measures

	1	2	3	4	5	6	7
1. BRIEF-A Global score	--						
2. Behavioral Regulation Index	.92**	--					
3. Metacognition Index	.95**	.80**	--				
4. Dysexecutive Questionnaire	.80**	.73**	.70**	--			
5. Self-Regulation Scale	-.65**	-.41*	-.78**	-.46**	--		
6.Overall mean RT	.02	-.02	.01	-.35*	.16	--	
7.Incongruent Trials RT	.03	-.01	.01	-.33	.15	.931**	--
8.Performance costs	.03	.03	.06	.24	-.11	-.13	-.39*

Note: *p < .05, **p < .01 , one-tailed

Mood, sleep, and psychological resilience

Positive relationships were found between mood and all measures of executive function; BRIEF-A Global score ($r(33) = .56$ $p < .001$, $r^2 = .32$), BRIEF-A Behavioral Regulation Index ($r(31) = .43$, $p < .05$, $r^2 = .18$). BRIEF-A Metacognition Index ($r(33) = .597$, $p < .001$, $r = .356$), and Dysexecutive Questionnaire ($r(36) = .49$, $p < .001$, $r^2 = .24$) as well as a negative relationship found between Self-Regulation Scale and mood ($r(39) = -.67$, $p < .001$, $r^2 = .45$). No statistically significant relationships were observed between mood and either HRV (Tonic score, $r(34) = .181$, $p > .05$; Phasic score, $r(34) = -.083$ $p > .05$) nor visual attention (mean overall RT, $r_s(33) = .028$, $p > .05$; incongruent distractor RT, $r_s(33) = -.001$, $p > .05$; performance costs, $r_s(33) = -.110$, $p > .05$).

Significant relationships were found between sleep quality and BRIEF-A Metacognition ($r_s(33) = .40$, $p < .05$, $r^2 = .16$) and Self-Regulation Scale ($r(39) = -.32$, $p < .05$, $r = .10$) Sleep quality was not significantly related to HRV (Tonic; $r(35) = .01$; Phasic; $r(35) = -.10$, $p > .05$), BRIEF-A Global score ($r(33) = .26$, $p > .05$), BRIEF-A Behavioral Regulation ($r(33) = .02$, $p >$

.05), Dysexecutive Questionnaire ($r(36) = .16$, $p > .05$), mean overall RT ($r_s(33) = -.10$, $p > .05$), incongruent distractor RT ($r_s(33) = -.09$, $p > .05$), nor performance costs ($r_s(33) = .12$, $p > .05$).

Significant negative relationships were found between resilience and BRIEF-A global score ($r(31) = -.67$, $p < .001$, $r^2 = .45$), BRIEF-A Behavioral Regulation score ($r(33) = -.569$, $p = .004$, $r^2 = .25$), the BRIEF-A Metacognition score ($r(33) = -.71$, $p = .000$, $r^2 = .50$); and the Dysexecutive Questionnaire ($r(36) = -.34$, $p < .05$, $r^2 = .12$). Additionally, a strong positive relationship was found between Self-Regulation Scale and resilience ($r(39) = .68$, $p <. 001$, $r^2 = .65$). Resilience was not associated with visual attention (mean overall RT, $r(33) =.15$, $p > .05$; incongruent distractor RT, $r(33) = .09$, $p > .05$; performance costs, $r(33) = -.06$, $p > .05$).

Post-Hoc Analyses

Independent *t*-test analyses were performed to examine potential group differences within measures used in analyses of executive function, visual attention and HRV. No group differences were found within measures of executive function. In regards to measures of visual attention, no significant group differences were found with respect to age (mean overall RT $t(39) = -.73$, $p > .05$; incongruent distractor RT $t(39) = -1.00$, $p > .05$); concussion history (mean overall RT $t(39) = -.32$, $p > .05$; incongruent distractor RT, $t(37) = -.28$, $p > .05$); previous experience with Dynavision (mean overall RT, $t(37) = .58$, $p > .05$; incongruent distractor RT, $t(37) = .78$, $p > .05$); or gender (mean overall RT, $t(37) = -.36$, $p > .05$; incongruent distractor RT , $t(37) = .23$, $p > .05$). However, significant, large effects were found in time of day when testing took place (early morning vs late afternoon) (mean overall RT; ($t(37) = 3.74$, $p < .001$, $d = 1.03$) (incongruent distractor RT; $t(37) = 3.73$, $p < .001$, $d = 1.06$); amount of time taken to complete visual task (overall RT; t(37) = 8.17, $p < .001$, d = 1.60); (incongruent distractor RT; $t(37)$ = 8.773, $p < .001$, d= 1.66).

CHAPTER IV

DISCUSSION

The purpose of this study was to assess the relationships among self-reported ability to successfully engage in goal-directed behavior (EF), ability to sustain visual attention and respond accordingly across a variety of competing demands (visual attention), and HRV in ROTC cadets. The study had a number of strengths in the design and methodology. A within-subjects, repeated measures approach was most appropriate to control for possible influences of HRV, such as high inter-individual variations of heart rate and the impact of external factors (Quintana & Heathers, 2014). Additionally, the sample size of the study meets recommended HRV-specific effect size guidelines and assumptions of at least 80% power (Quintana, Alvares, & Heathers, 2016). This study is the first of its kind to examine the relationships between EF, visual attention, and HRV using EF self-report measures, modified performance-based tasks, and smartphone collected HRV.

Hypothesis One

The first hypothesis was that executive function and HRV would be correlated. Specifically, I predicted that greater variability in beat-to-beat heart rate (tonic HRV) would be associated with better self-reported executive functioning (lower scores on the BRIEF-A and Dysexecutive Questionnaire, and higher scores on the Self-Regulation Scale). Furthermore, I predicted that stable HRV over time (lower phasic HRV) would be associated with better self-reported executive functioning (lower scores on the BRIEF-A and Dysexecutive Questionnaire, and higher scores on the Self-Regulation Scale RS). Only one measure of executive function, the BRIEF-A, significantly correlated with HRV; therefore, hypothesis one was partially supported.

Individuals who reported less frequent EF difficulty on the BRIEF-A possessed more stable phasic HRV. In addition, individuals who reported fewer difficulties that were specific to inhibition, shifting, monitoring, and emotional control as indexed by the BRIEF-A Behavioral Regulation composite score also possessed better (more variable) tonic HRV and more stable phasic HRV. These results echo previous findings in support of an association between executive function and responsivity of the autonomic nervous system (Thayer et al., 2000). The results also support the relationship between tonic HRV and capacity to self-regulate (Hansen et al., 2003, Thayer et al., 2009). The significant relationship between self-reported executive difficulty and HRV could suggest overlap in the functional connectivity between areas of the brain that support executive function and control of the autonomic nervous system, specifically areas that support switching between the sympathetic and parasympathetic nervous systems.

Hypothesis Two

The second hypothesis was that selective visual attention and HRV would be correlated. Specifically, I predicted a negative correlation between tonic HRV and response time and errors on a modified Erikson Flanker task. In addition, I hypothesize a positive correlation between phasic HRV and the modified Erikson Flanker task performance indicators. However, no significant relationships were found between any of the measures of visual attention or HRV, therefore this hypothesis is not supported.

Failure to find significance between visual attention and HRV implies that the constructs are not related. However, the non-significant findings may be explained by examining the intended use of the Dynavision apparatus and the Corsense sensors. I used the Dynavision apparatus as a tool for participants to use to respond to the arrow cues in the modified Flanker task. This usage does deviate from typical purpose of the Dynavision system. The Dynavision apparatus is designed to be a sport performance training tool that facilitates overall response time improvement (Klavora et al., 1994). The buttons on the apparatus are widely spaced, require full body movement, and thus, experimenters who use Dynavision typically ask participants to complete only a small number of trials. Within the visual attention literature however, the number of trials that are needed to accurately detect response time differences is much greater. Furthermore, in order to promote detection of novel and salient stimuli within one's visual field, the amount of incongruent trials should not have been equivalent to the amount of congruent trials presented within the modified Flanker task.

Another important limitation to this study is that there were methodological issues with the HRV data collection that must be noted. Approximately 17% of the total HRV was excluded because it was collected from a session that had fewer than 60 seconds of data acquisition time. This indicated either device or experimenter error. However, the majority of HRV data that were removed for this reason were from the same three participants who also had four or fewer valid data collection days.

In addition, homogeneity of answers (e.g., answering never for every item on a questionnaire) resulted in excluding self-reported data from three different participants. Response patterns like this suggest poor effort on the part of those participants (Protzko, Zeleleres, & Schooler, 2019). The presence of poor effort contradicts the initial selection criteria of participants by their superior officer, recall that participants were selected based on the commanding officer's perception of an individual's dependable and consistent performance over time. Also of note is that despite occasional poor effort, the participants in this study were not members of a clinical population but the Dysexecutive Questionnaire is not intended for a non-clinical population. Indeed, few studies use the Dysexecutive Questionnaire as a stand-alone measure of executive function. Therefore, failure to find relationships with all of the self-reported executive function measures may not indicate a lack of effect but may instead highlight the lack of construct sensitivity that some neuropsychological measures possess outside of their intended use.

Finally, another possible explanation for the lack of findings to support hypothesis two may have been higher levels of noise in testing environment. High levels of noise are associated with less reliable collection of HRV. Therefore, the lack of support for hypothesis two may simply highlight methodological flaws in the study and not necessarily that HRV and visual attention are not related.

Future Directions

The results of this study, combined with the uniqueness of the research design employed, allows for several future directions regarding the functional connectivity between executive function, visual attention, and HRV. First, future studies should examine participant effort to ensure that the individuals in the sample demonstrating an accurate representation of their cognitive and physiological abilities. Second, researchers should ensure that their cognitive tasks are carefully designed when new response tools, like the Dynavision apparatus are used. Finally, future studies should also account for influences of noise and stress within the testing environment when measuring cognition and HRV.

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APPENDIX A

IRB APPROVAL LETTERS

Institutional Review Board
Dept. 4915
615 McCallie Avenue
Chattanooga, TN 37403-2598
Phone: (423) 425-5867
Fax: (423) 425-4052
instrb@utc.edu
http://www.utc.edu/irb

MEMORANDUM

TO: Dr. Gary Wilkerson
Dr. Marisa Colston
Drs. Carrie Baker, Shellie Acocello

IRB # 16-121

FROM: Lindsay Pardue, Director of Research Integrity
Dr. Amy Doolittle, IRB Committee Chair

DATE: 10/5/2016

SUBJECT: IRB #16-121: Assessment of Injury History, Psycho-behavioral Factors, and Functional Capabilities of Physically Active College Students

The IRB Committee Chair has reviewed and approved your application and assigned you the IRB number listed above. You must include the following approval statement on research materials seen by participants and used in research reports:

The Institutional Review Board of the University of Tennessee at Chattanooga (FWA00004149) has approved this research project # **16-121*.***

Annual Renewal. All approved research is subject to UTC IRB review, at least once a year. Please visit our website (http://www.utc.edu/research-integrity/institutional-review-board/forms.php) for the Form B (continuation / change / completion form) that you will need to complete and submit if your project remains active and UTC IRB approval needs to be renewed for another year. Unless your research moves in a new direction or participants have experienced adverse reactions, then renewal is not a major hurdle. You as Principal Investigator are responsible for turning in the Form B on time (2 weeks before one year from now), and for determining whether any changes will affect the current status of the project. When you complete your research, the same change/completion form should be completed indicating project termination. This will allow UTC's Office of Research Integrity to close your project file.

Please remember to contact the IRB immediately and submit a new project proposal for review if significant changes occur in your research design or in any instruments used in conducting the study. You should also contact the IRB immediately if you encounter any adverse effects during your project that pose a risk to your subjects.

For any additional information, please consult our web page http://www.utc.edu/irb or email instrb@utc.edu

Best wishes for a successful research project.

THE UNIVERSITY OF TENNESSEE
CHATTANOOGA

Institutional Review Board
Dept 4915
615 McCallie Avenue
Chattanooga, TN 37403
Phone: (423) 425-5867
Fax: (423) 425-4052
instrb@utc.edu
http://www.utc.edu/irb

TO: Drs. Gary Wilkerson, Amanda Clark **IRB # 16-121**
Drs. Marisa Colston, Carrie Baker, Shellie Acocello, Jennifer Hogg
Kaila Rogers, Tyler Perry, Ashley Grillo, Abigail Rogers, Lauren Easter, and Madelyn Chadwell

FROM: Lindsay Pardue, Director of Research Integrity
Dr. Amy Doolittle, IRB Committee Chair

DATE: 2/5/2019

SUBJECT: IRB #:**16-121**: Assessment of Injury History, Psycho-behavioral Factors, and Functional Capabilities of Physically Active College Students

The Institutional Review Board has reviewed and approved the following changes for the IRB project listed above:

- Addition of Dr. Amanda Clark and graduate student Kaila Rogers
- Changes to the questionnaire as detailed in the form B application
- Addition of a $15 amazon giftcard
- Changes to the informed consent as detailed in the form B application

You must include the following approval statement on research materials seen by participants and used in research reports:

***The Institutional Review Board of the University of Tennessee at Chattanooga (FWA00004149) has approved this research project #* 16-121.**

Annual Renewal. All approved research is subject to UTC IRB review, at least once a year. Please visit our website (http://www.utc.edu/research-integrity/institutional-review-board/forms.php) for the Form B (continuation / change / completion form) that you will need to complete and submit if your project remains active and UTC IRB approval needs to be renewed for another year. Unless your research moves in a new direction or participants have experienced adverse reactions, then renewal is not a major hurdle. You as Principal Investigator are responsible for turning in the Form B on time (2 weeks before one year from now), and for determining whether any changes will affect the current status of the project. When you complete your research, the same change/completion form should be completed indicating project termination. This will allow UTC's Office of Research Integrity to close your project file.

Please remember to contact the IRB immediately and submit a new project proposal for review if significant changes

VITA

Kaila Ashton Rogers was born in Chattanooga, TN, to the parents of Kenny and Sherrie Rogers. She is the oldest of two children and has a younger sister, Kelsey. She attended Chattanooga School for the Liberal Arts from 1st through 8th grade and continued to Chattanooga School of the Arts and Sciences for 9th grade before transferring to Central High School to complete her high school education. After graduation, she took a brief hiatus from continuing her education to explore the world around her. In 2013, Kaila attended Chattanooga State Community College where she received her Associates of Science in Psychology in 2015. From there, she enrolled at University of Tennessee at Chattanooga to obtain a bachelor's degree. While taking courses, she was involved with research in Dr. Amanda Clark's Assessing Cognition Lab. This newfound love of research sparked the interest in pursuing higher education after graduation. She completed her Bachelor of Science in Psychology in 2017. Kaila was accepted into the University of Tennessee at Chattanooga Master of Research Psychology program in May 2017. She taught Introduction to Psychology and the Statistics in Psychology Laboratory over the course of her graduate career. Kaila graduated with a Master of Science degree in Research Psychology in December 2019. Kaila plans to work in industry after completion of this degree.